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# Craving what you imagine: How sensory mental imagery relates to trait food craving and BMI

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ABSTRACT

Mental imagery (MI), particularly visual imagery, is thought to play a key role in inducing food cravings, yet its relationship with trait food craving and adiposity remains underexplored. This study investigated how MI for multiple senses is related to the individual food craving trait and BMI. Experiment 1, conducted with a cohort of 291 individuals, used a partial Plymouth Sensory Imagery Questionnaire (PSI-Q) and the Food Craving Inventory. Experiment 2 expanded on this with a large sample (n = 1371) collected across NZ, the United Kingdom, and the United States, incorporating a full PSI-Q with an additional food dimension, the Spontaneous Use of Imagery Scale, as well as the Food Craving Questionnaire-Trait. Across both studies, weak positive correlations emerged between the vividness of olfactory MI scores and trait food craving. In Experiment 2, the vividness scores associated with Smell, Taste, Food, Sensation, and Feel were weakly correlated with the trait food craving measure. Interestingly, an individual's spontaneous use of visual MI, measured with the Spontaneous Use of Imagery Scale, was indirectly linked to BMI, mediated by an individual's food craving trait. These findings provide novel insights into the role of sensory MI in habitual food cravings and adiposity, while at the same time highlighting methodological gaps in current approaches to measuring individual sensory MI.

## 1. Introduction

Mental imagery (MI) refers to the cognitive ability to generate sensory experiences in the mind, in the absence of the associated external sensory stimuli. This ability has long intrigued philosophers, psychologists, and, more recently, neuroscientists and clinicians, due to its central role in planning, problem-solving, communication, and various other daily tasks (LeBoutillier & Marks, 2003; Rowe et al., 2001; Yoon & Narayanan, 2004). While research on MI has primarily focused on the visual modality, growing evidence supports its presence in the auditory, tactile/haptic, olfactory, and gustatory domains as well (Auditory MI: Halpern and Zatorre (1999); Hubbard (2013); Intons-Peterson (2014); Tactile/Haptic MI: c. f., Gallace (2013); Olfactory MI: Carrasco and Ridout (1993); Herz and Engen (1996); Stevenson and Case (2005); Perszyk et al. (2023); Gustatory MI: Kobayashi et al. (2004); Spence (2022)). It is rare for an individual to be completely lacking in MI within a specific sense, for instance, the estimate of visual aphantasia, i.e., the inability to generate visual mental images, ranges between 1.5 % and 3.0 % (Dance et al., 2022; Zeman, 2024). However, substantial inter-individual differences are evident in terms of the vividness or the frequency of experiencing images (Floridou et al., 2022). These marked individual differences have been linked to various behavioural outcomes (Burke et al., 2014; LeBoutillier & Marks, 2003; Moscovitch et al., 2013). In the research realm of eating behaviour, MI has primarily been studied for its role in inducing and modulating food craving (Kemps & Tiggemann, 2015).

Food cravings, broadly defined as an intense desire to eat a specific food (Weingarten & Elston, 1990), differ from general food preference by their heightened intensity of desire. While food preference refers to the "qualitative, affective evaluation of food" – reflecting the degree of

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experience of pleasure or displeasure (Mela, 2001), craving is characterised by a compelling urge or strong desire (Gearhardt, Rizk, & Treat, 2014). Cravings can be triggered and influenced by either external cues (e.g., food smells or images of food) or internal states (e.g., hunger or mood changes). This situational response is known as *state food craving*, a common experience for many people. However, the frequency and intensity of cravings vary significantly across individuals. Those classified as high food cravers experience cravings more intensely and more frequently than low cravers. This relatively stable tendency to experience cravings is referred to as *trait food craving*, which remains consistent over time and across various contexts (Richard et al., 2017). Trait food craving is particularly relevant because it is more strongly linked to eating psychopathologies, such as binge eating (Van den Eynde et al., 2012), thereby contributing to diet-related health issues. Understanding individual differences in trait food craving is therefore crucial for identifying diverse eating behaviours and developing effective interventions for maladaptive eating.

Although a range of physiological, emotional, and cognitive factors can trigger food cravings, the underlying cognitive mechanisms remain under investigation. The Elaborated Intrusion Theory of Desire, proposed by Kavanagh, Andrade, and May (2005), places MI at the centre of craving, suggesting that cravings begin with intrusive thoughts of the desired food, which then develop into more elaborate MI. According to this theory, sensory MI plays a crucial role by providing immediate reward through mental representations, thereby amplifying the desire for the specific food. While the theory has received considerable support, the specific cognitive process is yet to be fully understood. Empirically, the role of MI in the induction of cravings had been demonstrated with several different approaches. First, anecdotal reports suggest that cravings are often accompanied by vivid sensory images of craved food (Salkovskis & Reynolds, 1994; Tiggemann & Kemps, 2005). While visual MI of craved foods is reported most frequently, images of food aroma and taste are also frequently mentioned (May et al., 2004; Shahriari et al., 2020). Further, behavioural research has also shown that cravings can be provoked by simply asking the participants to imagine eating their favourite foods (Green, Rogers, & Elliman, 2000). Moreover, the intensity of craving has been shown to be positively correlated with the vividness of the mental images that an individual generates (Harvey, Kemps, & Tiggemann, 2005).

While substantial evidence supports the role of MI – predominantly visual, with minor evidence for smell and taste imagery – in the induction of food cravings, much less is known about how an individual's ability to generate MI interacts with their stable habit of food craving (i.e., trait food craving). Beyond eating behaviour, MI is well-established as a key driver of motivation and engagement in rewarding activities. Acting as a motivational amplifier, MI allows individuals to pre-experience activities and anticipate their potential to be rewarding (Holmes, et al., 2016). Thus, it is plausible to hypothesize that individuals with heightened MI abilities may experience stronger, more frequent and more persistent food cravings, while those with frequent cravings may, in turn, engage in more vivid and frequent MI of food or related sensory cues. Supporting this idea, studies in other domains, such as musical and sports training (Dhouibi et al., 2021; Talamini et al., 2023) – indicate that individuals who engage more deeply in an activity tend to generate more vivid MI related to it. Similarly, Tempere, de Revel, and Sicard (2019), in their review of wine expertise, indicate that MI plays an important role in wine discrimination and categorisation among experts, highlighting its significance in sensory driven expertise. Devoto et al. (2024) demonstrated that during a food-related fMRI task, high food cravers exhibited stronger activation in dopaminergic circuitry, as opposed to low food cravers. Their results suggest a functional coupling between the brain's reward system and higher-order visual regions involved in food craving, thus providing a neural basis for links between visual MI and trait food craving. These findings suggest that MI does not merely elicit transient (state) cravings but may also contribute to habitual craving trait. The precise nature of this relationship between MI and food craving trait remains an open area for exploration.

Relative to visual imagery, specific roles of gustatory or olfactory imagery in triggering food cravings remain underexplored. In a survey study by Tiggemann and Kemps (2005), undergraduate students were asked to recall their most recent food craving experience. Their results revealed that visual imagery played a dominant role, with 39.7 % of participants reporting the ability to picture/visualize the food. In contrast, gustatory and olfactory-related imagery terms were cited by 30.6 % and 15.8 % of the participants, respectively. This finding may be due to the richer vocabulary available for visual descriptors, or longer persistence of visual memories, or the relative ease of generating visual images as compared to images in the other senses (Carrasco & Ridout, 1993; Cowan, 2015; Köster, 2002). Nevertheless, the prominence of visual imagery over olfactory and gustatory descriptors is surprising, given the crucial role of chemosensation in the experience of food. Further, a study by Croijmans and Wang (2022) confirmed that imagery abilities of smell, taste, and mouthfeel all play an important role in wine appreciation and desire, calling for more research to explore contributions of multisensory imagery to food craving.

An extended question is whether an individual's MI abilities are related to their adiposity. Many previous studies had included trait food craving and BMI as secondary measures when studying visual imagery related to food. However, few had specifically tested the relationships between these variables. One notable exception is Patel et al. (2015), who examined the mediating roles of olfactory and visual MI in relation to trait food craving and BMI. Their results revealed that olfactory, relative to visual, imagery was a stronger predictor of BMI, although surprisingly no correlation was observed between MI and food craving. A recent follow-up study reported that olfactory MI is linked to food cue-reactivity and exerts an indirect effect on an individual's BMI (Perszyk et al., 2023). These results warrant further investigation.

Despite major progress in research on various aspects of the role of MI in food craving, there are a few notable research gaps in this area. First, there is a lack of consensus as to whether an individual's MI abilities are associated with trait food craving. Second, previous research has primarily focused on visual MI in regard to state food craving, with limited research of olfactory and gustatory MI, despite the pivotal role of chemosensory functions in food experience. In this context, the current research aims to address these gaps in the literature by systematically assessing the relationship of multisensory MI to trait food craving and BMI.

## 2. Experiment 1

### 2.1. Methods

Experiment 1 was conducted with participants from New Zealand aged 18 years or older. We aimed to recruit 279 participants. This sample size was estimated based on the correlation reported in Patel et al. (2015) which is one of the few studies that explored the relationship of visual and olfactory imagery to food craving (Pearson's correlation coefficient of 0.195 based on averaged correlation coefficient across visual and olfactory MI with FCI). With a weak correlation estimate, 85 % power and an α-level of 0.05, a minimum sample size of 233 was estimated, using G*Power 3.1.9.7 software (Faul et al., 2009). An additional 20 % attrition was factored in during recruitment. The participants were recruited via social media, flyers, mailing lists and word of mouth. Eligible participants undertook this online study, which comprised a partial Plymouth Sensory Imagery Questionnaire (Vision, Olfaction, Gustation), Food Craving Inventory, and a demographic questionnaire. Consent was obtained prior to the participant's taking part in the study. Approval for the study was obtained from the University of Otago Ethics Committee (23/093). The study was developed and distributed with Qualtrics XM (Qualtrics, 2020). This study was not openly pre-registered, but the protocol was pre-determined and approved in accordance with university regulations.

#### 2.1.1. Food Craving Inventory (FCI)

Habitual food cravings were assessed using the Food Craving Inventory (White, Whisenhunt, Williamson, Greenway, & Netemeyer, 2002; FCI). This scale is a self-report measure of specific food cravings. It consists of 28 items measuring the frequency of cravings for specific foods (e.g., brownies, bacon). The original version was developed and validated with a community sample in the US. Subsequently, the scale has been validated in other countries and languages (Meule, 2020). The version used in the present study has been adapted and validated in Australia (Stapleton et al., 2022), which shares a similar food environment with New Zealand. Notably, this scale includes animal products (e.g., bacon) to assess participants' general tendency to experience food cravings, irrespective of the actual patterns of consumption. To contextualise the responses, participants' dietary regimens were recorded at the end of the questionnaire, enabling comparisons between plant-based and non-plant-based dieters.

#### 2.1.2. Plymouth Sensory Imagery Questionnaire (PSI-Q)

The Plymouth Sensory Imagery Questionnaire (PSI-Q), developed by Andrade et al. (2014), measures the vividness of MI across seven dimensions, including the five sensory modalities, along with "Bodily sensation" and "Feeling". The scale comprises 35 items, with five items per dimension. The participant is asked to voluntarily form an image of each item and rate its vividness on an 11-point scale (0-no image; 10-as vivid as real life). For this experiment, we only included three sensory dimensions of the PSI-Q, namely Vision, Olfaction, and Gustation. Some examples include the appearance of "a sunset", "a bonfire", the smell of "a rose", "newly cut grass", or the taste of "black pepper", "lemon". Readers are referred to Andrade et al. (2014) for the full item list.

#### 2.1.3. Demographic questionnaire

The participants completed a demographic questionnaire which included, age, gender, ethnicity, how long they had lived in NZ, household income, dietary regimen, and estimated height and weight (for calculating BMI). The participants were also asked if they had any known neurological or psychiatric conditions that might affect their sensory imagination, as well as their typical diet.

### 2.2. Analysis

Participants' characteristics, including age, ethnicity, and BMI are summarised with descriptive statistics. Univariate analyses were then applied to the FCI and PSI-Q sub-dimension measures to understand the amount of variability, and potential effect of gender, age, and BMI on these measures. Bonferroni corrections were applied to correct for any multiple comparisons. Pearson's correlations were applied to assess potential relationships between PSI-Q measures, FCI, and BMI. Mediation analyses were applied to test whether the PSI-Q was related to BMI, mediated by FCI. The significance of the indirect effect between PSI-Q and BMI was tested via bootstrapping procedures with 500 samples. The Average Causal Mediation Effect (ACME) was calculated to estimate the extent to which the mediator explains the relationship between the dependent and independent variables. A significant mediation effect is indicated when the CI for ACME does not include 0, suggesting a statistically significant indirect effect of the mediator. Additionally, mediation analyses were applied to further clarify the role of FCI on the relationship between PSI-Q and BMI. In cases where a direct relationship was not observed, mediation analysis was still conducted following the recommendations of O'Rourke and MacKinnon (2018); Rucker et al. (2011). All statistical analyses were performed using R (version 1.1.463, MA, USA). Data and analysis scripts of the study are available on OSF (Data: https://osf.io/3m7fc; Analyses: https://osf.io/4pbyu).

### 2.3. Results

A total of 291 participants submitted complete responses in the online study. Participant characteristics are presented in Table 1. Due to the open recruiting approach, the participants' genders were imbalanced, being predominantly female.

#### 2.3.1. Inter-Food Craving Inventory scores

Substantial variability was observed in terms of the FCI scores, with an average score of 2.47 (SD = 0.66; range = 0.84–4.56). An ANCOVA was performed to test for differences in FCI scores across Gender, with Age and BMI as continuous covariates. None of these factors showed significant results, with only BMI approaching significance ($p = 0.07$). A separate ANOVA was applied to assess whether plant-based dietary regimens had an impact on the FCI, with the results revealing non-significant differences ($p = 0.27$).

#### 2.3.2. Inter-individual differences in sensory imagery abilities

A mixed-model ANCOVA was applied to test for differences in PSI-Q scores across the sub-dimensions (within-subject variable). The results revealed significant differences in the vividness scores between the three dimensions ($F_{(2,466)} = 10.42$, $p < 0.001$, $\eta^2 = 0.043$). Pairwise comparisons, with *Bonferroni* correction, revealed that the visual vividness scores (M = 41.04; SD = 8.90) were significantly higher than those of smell (M = 37.43; SD = 10.24) and taste (M = 37.44; SD = 10.41; $p < 0.05$). Additionally, the model did not reveal any significant between-subject effect due to Gender, Age, or BMI on the PSI-Q scores.

#### 2.3.3. Relationship between MI and FCI and BMI

Pearson's correlation revealed a significant positive relationship between the overall PSI-Q and FCI score (r = 0.12; $p = 0.041$). Further correlation analyses across the sub-dimensions of PSI-Q suggested that only the vividness of olfactory imagery showed a weak positive correlation with FCI (r = 0.13; $p = 0.027$). Neither visual nor gustatory imagery vividness revealed significant relationships (Fig. 1). Notably, none of the PSI-Q scores was correlated with BMI, but the FCI scores were positively correlated with BMI.

Mediation analyses were performed to further elucidate the relationships between individual imagery vividness, food craving, and adiposity. Specifically, the analysis examined whether an individual's imagery abilities across different modalities, as measured by PSI-Q scores for visual, olfactory, gustatory, and a composite score combining the three dimensions, were related to BMI. It additionally tested whether the relationship was mediated by trait food craving. The results revealed no direct association between MI vividness and BMI. However, the olfactory dimension of the PSI-Q scores highlighted a significant, yet weak indirect relationship with BMI, mediated by the FCI scores (see Fig. 2). The mediation effects were quantified by the Average

**Table 1**
Participant characteristics for Experiment I, including results from univariate variate analyses (T-test or Chi-Square test) for comparison across genders.

| | Total (n = 291) | Male (n = 40) | Female (n = 238) | Test statistic | *p*-value |
|---|---|---|---|---|---|
| **Age (years) Mean (SD)** | 39 (13) | 32 (10) | 40 (13) | 4.96 | 0.002 |
| **Ethnicity N (%)** | | | | −1.03 | 0.304 |
| Māori | 26 (8.9) | 2 (5.0) | 24 (10.1) | | |
| Pacific Islander | 6 (2.1) | | 6 (2.5) | | |
| New Zealand European | 217 (74.6) | 32 (80.0) | 176 (73.9) | | |
| Asian | 29 (10.0) | 6 (15.0) | 23 (9.7) | | |
| Other | 9 (3.1) | | 8 (3.4) | | |
| **BMI Mean (SD)** | 28.11 (8.00) | 24.65 (3.67) | 28.71 (8.44) | 3.11 | 0.027 |

* Another gender n = 4 (1.4 %); prefer not to say n = 9 (3.1 %).

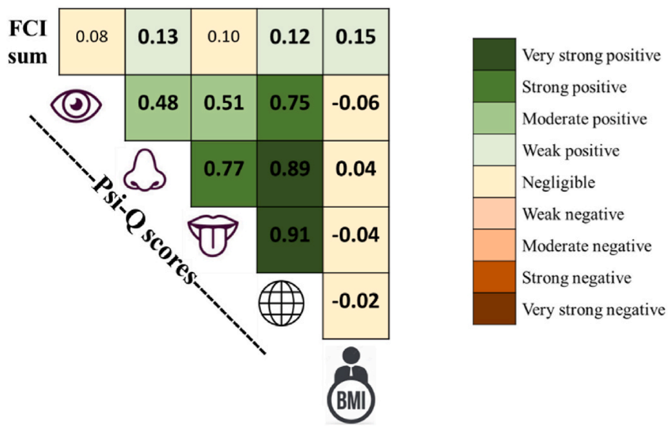


**Fig. 1.** Correlation matrix illustrating bivariate correlations between measures, including Food Craving Inventory (FCI) scores, Plymouth Sensory Imagery Questionnaire scores (Visual, Olfactory, Gustatory, and the Sum), and self-reported BMI measures in Study 1. Numbers in bold refer to significant correlation coefficients ($p < 0.05$). The legend describes the strength of correlation coefficients by colour – Negligible ($0<r\leq|0.2|$); weak correlation ($|0.2|<r\leq|0.4|$); moderate correlation ($|0.4|<r\leq|0.6|$); strong correlation ($|0.6|<r\leq|0.8|$); very strong correlation ($|0.8|<r<|1.0|$) (Swinscow & Campbell, 1997). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Causal Mediation Effect (ACME), which represents the change in BMI attributable to changes in the mediator (i.e., FCI), while holding the direct effect constant. Path values correspond to unstandardised regression coefficients. These results suggested that an individual's vividness of olfactory MI can predict their BMI via food craving trait. Nevertheless, while this relationship was significant, it is important to note that the effect of smell vividness on FCI was modest.

*2.3.4. Interim discussion*

The results of Experiment 1 revealed a weak positive correlation between the PSI-Q averaged across the selected domains and FCI. With regard to specific dimensions, only the olfactory PSI-Q was positively correlated with the trait food craving measure. Regardless, none of these vividness measures of MI was correlated with BMI measures. These findings echoed the findings from Patel et al. (2015) contradicting the large body of literature stressing the role of visual MI in food craving.

The limited research exploring the link between MI and food cravings has predominantly focused on an individual's voluntary MI abilities. Typically, participants are instructed to form and maintain specific MI upon request. The Spontaneous Use of Imagery Scale (SUIS) was developed to assess an individual's spontaneous use of imagery in daily life (Kosslyn et al., 1998; Mast et al., 2003; Nelis et al., 2014), and is increasingly regarded as a *trait* measure of *visual* MI. This scale asks participants to rate the appropriateness of using visual MI across various scenarios. Notably, the SUIS does not fully address involuntary-occurring MI, as it assesses imagery use triggered by specific situational prompts rather than completely spontaneous formation of MI. Nevertheless, the SUIS provides a differential measure of an individual's habit of using MI in daily life. Currently, no equivalent scale current exists to measure the spontaneous uses of MI outside of the visual modality.

In this context, Experiment 2 was designed as a replication study with a larger sample size, incorporating four key modifications: (1) the inclusion of the full PSI-Q with an additional food-related dimension; (2) the addition of the SUIS survey; (3) replacement of the FCI with Food Craving Questionnaire Trait (FCQ-T) to better account for potential differences between omnivores and vegetarians; and (4) an increased sample size to support the expanded measures.

## 3. Experiment 2

### *3.1. Methods*

The participants were recruited using online platforms, with a target sample size of 1679. The sample size was determined based on the effect size observed in Experiment 1 (with the weakest correlation observed between PSI-Q Visual and FCI), with a power of 85 % and alpha of 0.05, resulting in a required minimum of 1399 participants. An additional 20

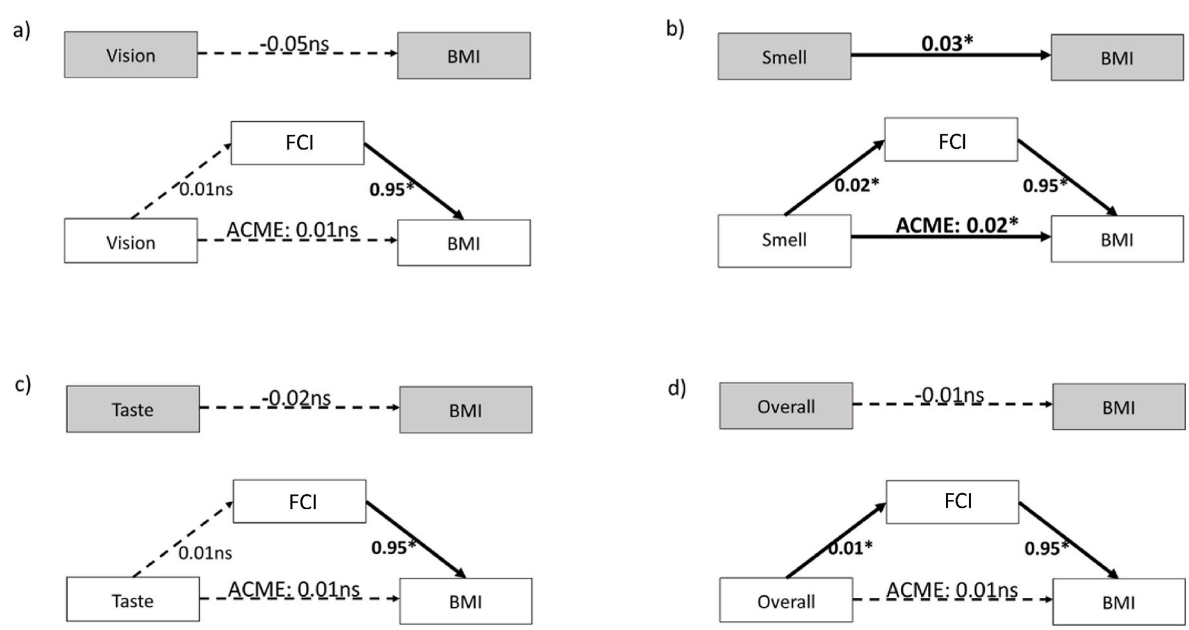


**Fig. 2.** Mediation analyses results from Experiment 1, examining the mediating role of Food Craving Inventory (FCI) scores in the relationship between BMI and Plymouth Sensory Imagery Questionnaire (PSI-Q) scores for (a) vision, (b) smell, (c) taste, and (d) overall imagery. Direct effects between each PSI-Q score and BMI are presented at the top of each subfigure. Mediation effects are quantified by the Average Causal Mediation Effect (ACME), representing the change in the Dependent Variable attributable to changes in the mediator, while holding the direct effect constant. Path values indicate unstandardised regression coefficients, with significance denoted by an asterisk (*) and non-significance by "ns." Solid lines represent significant relationships.

% was then counted for potential withdrawals. Data collection was carried out concurrently across three English-speaking countries (i.e., NZ, the United States, or the United Kingdom). This multi-country collection approach was implemented to expedite data collection and was not based on any specific hypotheses related to cross-country comparisons. The inclusion of the US and UK, alongside NZ, was guided by two primary considerations: (1) English is the primary language in both countries; (2) our ethics approval permitted access to survey responses from these regions. As a part of the eligibility, the participants are required to have English as their primary language. All other screening processes were similar to those of Experiment I. Approval for the study was obtained from the University of Otago Ethics Committee (24/410). The study was developed and distributed with RedCap (Version 13.10.0, Vanderbilt University). Demographic information, including age, ethnicity, income, and education, were collected. The participants were able to report their height and weight in metric or imperial measures for enabling BMI calculation. Participants completed the full PSI-Q, along with additional food-related items, including fried chicken, cookies, barbecue, fresh herbs, and garlic. While the food dimension was not formally validated, we followed a similar approach to that used by Patel et al. (2015).

### 3.1.1. Food cravings questionnaire trait – reduced version

The Food Cravings Questionnaire-trait (FCQ-T-r) was developed by Meule et al. (2014) on the basis of the full 39-item FCQ-T by Cepeda--Benito et al. (2000). This reduced scale measures habitual food cravings with 15 items, with each scored on a 6-point scale ranging from “Never” to “Always”. The questionnaire comprises nine subscales, enquiring the participants’ food craving trait in (1) intention to consume food; (2) anticipation of positive reinforcement; (3) relief from negative states; (4) lack of control over-eating; (5) preoccupation with food; (6) hunger; (7) emotion; (8) cues that trigger craving; and (9) guilt Cepeda-Benito et al. (2000)).

### 3.1.2. The Spontaneous Use of Imagery Scale (SUIS)

The Spontaneous Use of Imagery Scale (SUIS) is a 12-item self-report scale for measuring the spontaneous use of MI in daily life (Kosslyn et al., 1998; Mast et al., 2003). Participants are presented with common life scenarios where MI may be experienced. They were asked to rate the ‘appropriateness’ – in terms of applicability of MI – from ‘always completely appropriate’ to ‘never appropriate’. For example, one scenario state: “If I am looking for new furniture in a store, I always visualize what the furniture would look like in particular places in my home”. As previously noted, the SUIS predominantly concerns the use of visual imagery. Furthermore, and importantly in the context of the present study, none of the 12 items in the SUIS address food or food-related behaviour.

## 3.2. Results

A total of 1677 people entered the survey, with 306 removed for implausibly speedy responses (completion in less than 4 min), or incomplete responses on the primary measures. A total of 1371 individuals completed the survey, with over 400 in each of the three testing countries. Participants’ information is summarised in Table 2. Statistical differences were observed across the countries in terms of Age, Gender, and BMI. For subsequent analyses, some participants were excluded in specific analyses due to incomplete responses to some measures (e.g., BMI).

### 3.2.1. Individual differences in mental imagery measures

Substantial inter-individual variabilities in PSI-Q scores were observed, ranging from 0 to the maximum score of 50 for individual modalities. Fig. 3 illustrates the frequency distributions of PSI-Q scores across the eight sub-dimensions. For ease of comparison, the top panel displays the distributions for the five sensory dimensions, while the lower panels present those associated with the Bodily sensation, Feel, and Food dimensions. As shown, all distributions are left-skewed.

Using an arbitrary cut-off of 10 points (out of 50) to indicate a lack of MI, Sound had the lowest proportion of individuals meeting this criterion (1.17 %), followed by Vision and Touch (both 1.75 %), Taste (2.19 %) and Smell (3.43 %). When the threshold was extended to 20 points, the proportions increased to 2.77 % for sound, 3.43 % for Vision, 3.79 % for Touch, 7.15 % for Taste, and 9.70 % for Smell. Conversely, the proportion of individuals who reported full scores on a sensory dimension of the PSI-Q (i.e., 50 points) was the highest for Vision (20.06 %) followed by Sound (19.47 %), Touch (15.97 %), Taste (11.23 %), and Smell (8.24 %).

Differences across the PSI-Q dimensions were also evident in the actual scores. The results of the mixed-model ANCOVA revealed a significant within-subject effect ($F_{(7, 1278)} = 15.89$, $p < 0.001$, partial $\eta^2 =$

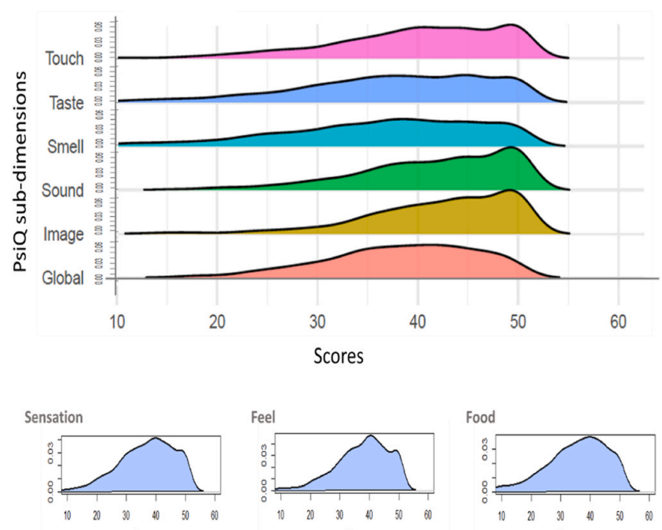


**Fig. 3.** Frequency distributions of Plymouth Sensory Imagery Questionnaire (PSI-Q) scores with kernel density estimation. Scores range from 0 (indicating no ability to form imagery for any of the five listed items within a specific modality) to 50 (indicating imagery as vivid as the actual sensory experience for all five items). Notably, the “Taste” dimension of the PSI-Q uses flavour instead of gustatory stimuli.

**Table 2**
Participant information across New Zealand (NZ), United Kingdom (UK), and United States (US) for Experiment 2.

| | | NZ | UK | US | | |
|---|---|---|---|---|---|---|
| | N = 1371 | N = 403 | N = 480 | N = 488 | Test Statistics | *P*-Value |
| Age (years) M (SD) | 39 (13) | 38 (14) | 43 (13) | 36 (12) | 10.69 | <0.001 |
| Gender N (%) | | | | | 57.49 | <0.001 |
| Male | 563 (41.1) | 99 (24.6) | 229 (47.7) | 235 (48.2) | | |
| Female | 747 (54.5) | 284 (70.5) | 235 (49.0) | 228 (46.7) | | |
| Other | 61 (4.4) | 20 (5.0) | 16 (3.3) | 25 (5.1) | | |
| BMI | 26.49 (5.06) | 26.17 (4.89) | 26.001 (4.72) | 27.25 (5.06) | 7.78 | <0.001 |

0.081). As illustrated in Fig. 4, Visual, Sound, and Touch yielded the highest vividness scores. In contrast, Smell, Sensation, and Food were associated with the lower scores, although the effect sizes of these differences were small. The model found neither Gender nor BMI had effects on the PSI-Q scores ($p > 0.05$). Scores of separate countries are provided in the Supplementary Material.

As an exploratory analysis to understand whether age has any effect on MI, Pearson's correlations were applied to the PSI-Q global or SUIS scores. Intriguingly, Age was found to be positively correlated with PSI-Q overall score ($r = 0.119$, $p < 0.001$), but negatively correlated with SUIS ($r = -0.075$, $p = 0.007$). Both correlations were significant, albeit being weak.

### 3.2.2. *Individual differences in trait food craving*

The FCQ-T scores varied substantially across the participants, ranging from 15 to 90. The averaged score is 45.4 (SD = 15.3). An ANCOVA was applied to test for differences in FCQ-T scores as a function of country and gender, with BMI measures as a covariate. A significant main effect was observed for both factors (Country: $F_{(4,1325)} = 7.26$, $p < 0.001$, partial $\eta^2 = 0.12$; Gender: ($F_{(2, 1325)} = 14.29$, $p < 0.001$, partial $\eta^2 = 0.023$). Females and NZ respondents reported significantly higher scores than their counterparts.

BMI was shown to be a significant covariate ($F_{(4,1325)} = 2.89$, $p = 0.021$). Post-hoc analyses were, therefore, performed to understand the above interaction effect, treating BMI as a categorical variable with different weight groups (i.e., normal weight, overweight, with obesity; WHO Standards, 2023). The results revealed that individuals with obesity reported significantly higher FCQ-T scores (M = 51.97, SD = 16.16) compared to the overweight (M = 43.98, SD = 14.89) and normal-weight group (M = 43.51, SD = 14.61). No significant difference was found between the normal weight and overweight groups in either the NZ or USA data (OB > NW = OW). However, in the UK data, FCQ-T scores showed significant differences between all weight groups, following the pattern OB > OW > NW.

### 3.2.3. *Relationship between mental imagery and food craving or BMI*

Partial correlations, controlling for Country, Age, and Gender, revealed significant positive relationships between MI measures and food cravings (see Fig. 5). On an overall level, the PSI-Q score was positively correlated with FCQ-T ($r = 0.072$, $p = 0.014$), suggesting that the vividness of MI is associated with the food craving trait. Furthermore, correlations between specific dimensions of PSI-Q and FCQ-T were assessed in detail. The results of Partial Correlations indicated significant results for Smell, Taste, Sensation, and Food, with R coefficients ranging between 0.06 ($p = 0.040$) and 0.08 ($p = 0.006$). Additionally, a moderate association was observed between SUIS and FCQ-T, with a relatively higher R coefficient of 0.19 ($p < 0.001$). However, no significant correlation was observed between MI measures and BMI.

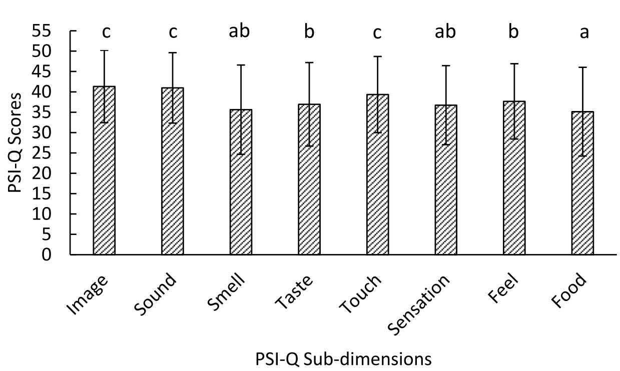


**Fig. 4.** Bar graph of averaged Plymouth Sensory Imagery Questionnaire scores for individual dimensions in Experiment 2. Error bars represent the value of standard deviations. The bars denoted with different letters represent significantly different values ($p < 0.05$).

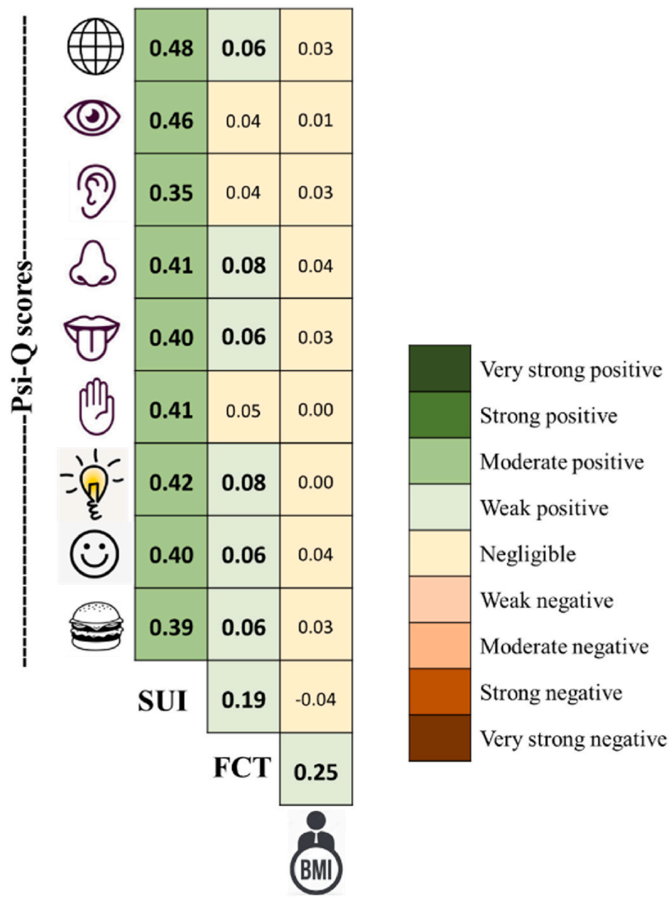


**Fig. 5.** Correlation matrix showing partial correlation across Psi-Q scores (i.e., overall, image, sound, smell, taste, touch, sensation, feel, food), SUI score, FCQ-T, and BMI collected in Experiment 2, controlling for age, gender, and country. Significant correlation coefficients are in bold.

Mediation analyses, ACME, further explored the mediating role of food craving on the relationship of sensory MI and BMI. Each mediation analysis focused on an individual MI measures (i.e., nine PSI-Q measures and SUIS). Fig. 6 presents the mediation figures based on the PSI-Q overall and SUIS. The path values correspond to the effect of variables on the outcomes, in a form of unstandardised regression coefficients. As shown, none of these MI measures had a direct relationship with BMI, however, the food craving measure (i.e., FCQ-T) had an indirect complete mediation effect on the relationship between SUIS and BMI. These results imply that an individual's habitual use of spontaneous MI drives the intensity of their food cravings, which in turn, influences one's adiposity. However, we did not replicate the results from Experiment 1 with regard to the mediating effect of food craving measures on PSI-Q Smell and BMI.

Notably, separate ACME mediation analyses were performed for specific dimensions of the PSI-Q. These analyses did not detect significant direct or indirect relationships between PSI-Q and BMI, consistent to the findings from Experiment 1.

## 4. Discussion

### 4.1. *Main findings*

The present study systematically explored the relationship between individual MI abilities and trait food craving, uncovering several key

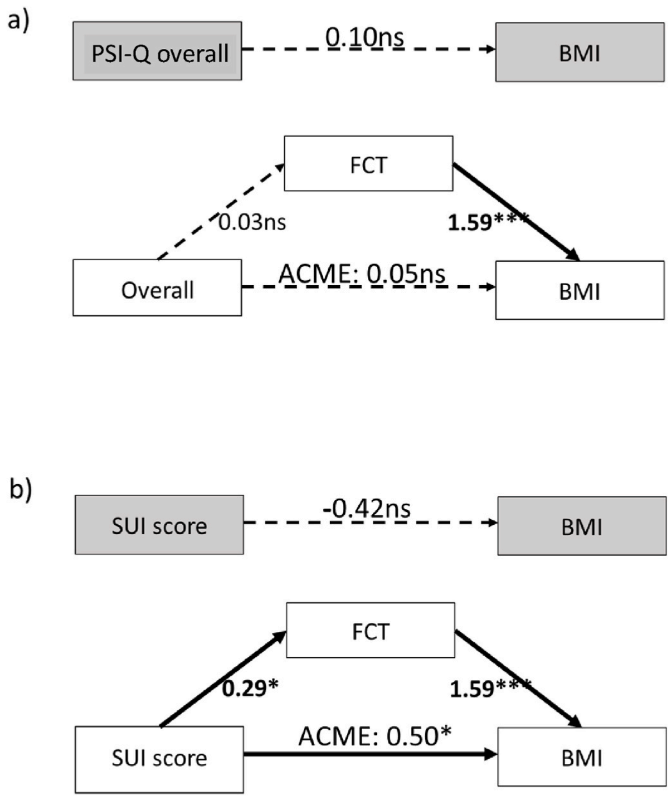


**Fig. 6.** Results of mediation analyses from Experiment 2, examining the mediating role of food craving trait (i.e., Food Craving Questionnaire -Trait scores) on the relationship of (a) overall Plymouth Sensory Imagery Questionnaire (PSI-Q) scores, or (b) Spontaneous Use of Imagery (SUI) scores and BMI. Direct effects are shown at the top of each panel. Mediation effects are quantified by the Average Causal Mediation Effect (ACME), representing the change in the dependent variable attributable to changes in the mediator, while holding the direct effect constant. Path values represent unstandardised regression coefficients, with significance denoted by an asterisk (*) and non-significance by "ns". Solid lines represent significant Average Causal Mediation Effect (ACME).

insights through two independent experiments. In summary, self-reported vividness of olfactory, gustatory, bodily sensation, and food-related imagery exhibited weak correlations with trait food craving. While the well-established strong association between food cravings and BMI was replicated, no significant relationship emerged between vividness measures of MI an BMI. Notably, an individual's spontaneous use of visual imagery was indirectly linked to BMI, with trait food craving mediating this relationship.

One of the compelling findings was the consistent positive correlation between an individual's smell imagery vividness and trait food craving across both experiments. The results of Experiment 1 additionally revealed a possible relationship between olfactory MI vividness and BMI, which was mediated by food cravings. These results are in line with findings by Perszyk et al. (2023), who showed that participants with stronger olfactory MI reported higher scores for food cravings, particularly for liked foods. With regard to taste imagery, only Experiment 2 observed a weak positive correlation to the food craving trait. The study also examined the food-specific dimension of the PSI-Q. Although we observed a relatively high proportion of individuals reporting challenges in creating MI of food flavours (9.6 % scoring below 20 points on the PSI-Q dimension), scores of this dimension are significantly and positively correlated with the measure of trait food craving. These results echo Patel et al. (2015), who observed a moderate correlation between food imagery and food craving, using a novel measure of Vividness of Food Imagery Questionnaire (VFIQ). These findings highlight the potential significance of food-specific imagery in craving experiences and point to a gap in standardised measures for assessing such imagery. While both the VFIQ used by Patel et al. (2015) and the PSI-Q Food dimension show promise, further validation of these measures remains necessary.

In contrast to olfactory and gustatory MI, visual MI showed little association with food cravings. Although a higher proportion of participants reported the ability to generate vivid visual imagery (20.6 % with maximum PSI-Q visual scores), this vividness was not significantly correlated with trait food cravings or BMI. Additionally, there is no evidence to suggest that visually-aphantasic individuals (with "blind mind's eye") exhibit a lower tendency for food craving trait or have a lower BMI. These results contrast with smell and taste (flavour) imagery, which were reported vividly by fewer participants (8.24 % and 11.23 % with maximum PSI-Q dimension scores, respectively), yet demonstrated clearer associations with food cravings. These findings align with Patel et al. (2015), who similarly found no significant relationship between visual MI and food craving or BMI, but observed a positive association between olfactory MI and BMI. These findings challenge previous assumption emphasising the dominance of visual imagery in *state* food cravings (Kemps & Tiggemann, 2015). Instead, they support the broader understanding that chemosensory functions are fundamental to flavour perception and may play a dominant role in driving food-related thoughts and behaviours (Prescott. 2015; Spence, 2022, but see Spence, 2024b for a comparison of chemosensory MI and perception). In real-life contexts, these findings suggest that cues emphasising food-related smell or taste – such as highlighting aromas or flavours through verbal, or sensory-enriched descriptions – may be more effective in triggering food cravings, particularly among individuals highly responsive to these sensory images. This may have implications to food marketing strategies and a deeper understanding of the sensory influences on consumer purchasing behaviour.

Further, previous research has suggested that visual and auditory MI produce the most vivid images, while olfactory and gustatory imagery are generally less vivid. Despite lower vividness scores for chemosensory MI, participants were able to generate vivid imagery across all sensory domains, with mean vividness scores exceeding 7, out of 10. Schifferstein (2009) similarly supported the suggestion that MI exists for all sensory modalities, but some modalities are more likely to be evoked in specific scenarios. In Schifferstein's case, the participants were asked to imagine a scenario of their own choosing and with a particularly strong involvement of a specific sensory modality. With this method, food and beverage scenarios dominated smell and taste imagery. Schifferstein's findings not only reiterated the particularly close relationship between chemosensory MI and food-related behaviour, but also implied that the context or task directly influence the vividness of MI in a specific modality.

The current study contributes to the growing body of research exploring the potential relationships between individual imagery abilities and adiposity. Our results did not reveal a strong correlation between the vividness of one's MI and adiposity. Notably, only the olfactory dimension of the PSI-Q scores in Experiment 1 was found to predict BMI by influencing the strength of an individual's trait food craving; however, we were not able to replicate this particular finding in Experiment 2. These results should be considered in light of Perszyk et al. (2023), who demonstrated that inter-individual differences in odour MI – assessed through a cognitive paradigm rather than self-report measures – significantly impacted BMI via food-cue reactivity. Although these findings appear to be inconsistent, the weak or absent relationship between MI vividness and BMI is not entirely unexpected. Croijmans and Wang (2022) examined the associations between wine-related sensory imagery and desire. Their finding indicated a positive correlation, however, they also showed that differences in desire among high and low imagers could be easily mitigated by providing wine descriptions. This suggests that while individual MI may be linked to the desire for specific foods, not all cravings necessitate MI. External sensory cues or information also trigger food cravings, independent of whether they evoke MI.

The results from the SUIS measure offered novel insights into the relationship between habitual uses of MI and trait food cravings. A stronger correlation was observed between SUIS and FCQ-T scores ($r = 0.19$) compared to the vividness-based PSI-Q measures ($r < 0.1$), implying that the frequency or habit of using imagery use, as opposed to the quality of voluntary imagery, is more closely linked to food cravings. Additionally, we observed a causal mediation relationship between the SUIS and an individual's BMI, mediated by food craving trait. This finding highlights the key role of 'involuntary' or 'spontaneously-occurring' MI in relation to food cravings. In a way, this finding is intuitive, as food-related thoughts may spontaneously arise either through crossmodal interactions of associated sensory cues, or by voluntarily evoking sensory MI. Supporting this idea, research in consumer psychology has previously demonstrated that the presentation of food images can trigger embodied mental stimulation, leading individual to mentally imagine eating the food (Elder & Krishna, 2012). Furthermore, found that engaging in imagined consumption could alter portion sizes effects and influence consumption behaviour (Petit et al., 2017). Future research could explore how one's trait food craving relates not only to their propensity for spontaneous engaging in food-related MI but also to their ability to intentionally use MI to regulate consumption.

This study also contributes to ongoing discussions about MI abilities across the senses, adding novel data into inter-individual differences in MI. To date, most research has focused on the prevalence of 'visual aphantasia', with Zeman et al. (2020) recommending a cut-off point of 25 on the VVIQ scale. Using the criterion, several studies have estimated that approximately 1.5 % of population may be visually-aphantasic. In contrast, relatively little is known about the prevalence of 'mind anosmia' (inability to imagine smells) or 'mind ageusia' (inability to imagine tastes). Our study provided some first-handed data, finding that approximately 1.17 % of participants reporting difficulty imagining familiar sounds, 1.75 % struggled with imagining tactile sensations. These percentages are compared to 2.19 % reporting difficulties imagining taste (flavour rather than gustatory stimuli) and 3.43 % who reported difficulties imagining smell in the current study. Among individuals reporting imagery abilities, gender appeared to play a minimal role. Interestingly, age exhibited a weak positive relationship with imagery vividness but a negative relationship with the spontaneous use of visual imagery. These findings partially align with previous research documenting the negative impact of ageing on visual imagery (Gulyás et al., 2022). However, they also highlight the need for further investigation into how ageing affects imagery abilities across the non-visual senses. It is possible that distinct sensory modalities follow unique progressive trajectories. For examples, olfaction – commonly affected by ageing – might exhibit enhanced MI as a compensatory mechanism in older adults.

Minor cross-country differences were also observed, with US respondents reporting slightly higher food craving and MI scores. Although these differences reached statistical significance, they were not substantial. A plausible explanation for the relatively elevated scores in the US could be cultural differences in scale-use behaviour, a phenomenon frequently reported in prior scale-based studies (Dolnicar & Grün, 2007; Lee et al., 2002).

### 4.2. Limitations

The present study has a few limitations that should be acknowledged. First, all measures relied on self-report, which, despite the validation of these scales, may limit their ability to accurately capture inter-individual differences in MI and food craving tendencies. Notably, BMI was calculated based on self-reported height and weight, a method known to be prone to misreporting (Yannakoulia et al., 2006, though see Lipsky et al., 2019) Additionally, while several significant relationships were identified, it is important to emphasise that their effect sizes were modest. The Food dimension of the PSI-Q was adapted from the VFIQ applied in Patel et al. (2015), but it was not empirically validated. Additionally, our recruitment approach did not allow for strict control over demographical variables. Although there is no theoretical rationale to hypothesize differences in the imagery abilities on a country or cultural basis, we caution the readers with regard to cross-country differences in the testing samples. There was also a small discrepancy between the targeted and collected sample sizes, due to factors such as incomplete responses and practical recruitment constraints. Additionally, the current studies were limited to univariate assessments of sensory dimensions, restricting the ability to examine how different modalities interact in shaping food cravings. For instance, it is possible that the combined vividness of visual and taste imagery, rather than individual sensory factors alone, plays a more significant role in craving experiences. Future research should explore interaction-based models to better capture these complex relationships and provide a more comprehensive understanding of how multisensory imagery influences food cravings.

### 4.3. Future directions

Our study highlights several areas for future research, particularly regarding the methodologies used to measure MI in relation to food behaviour. Existing imagery scales, such as the PSI-Q, present certain limitations. While the PSI-Q is the only available validated MI scale that captures multiple sensory modalities, its smell and taste dimensions are not fully congruent with the definitions of primary senses. For example, items such as "pepper" are categorised under Taste, but the spice normally evokes sensations across taste, smell, and the trigeminal senses (i.e., pungency) (Spence, 2024a). Similarly, descriptors such as "burnt wood", "lemon", "sea water" often engage multiple sensory systems, complicating the interpretation of modality-specific MI scores.

Another notable gap is the lack of a validated, food-specific imagery scale. While some items in the PSI-Q are food-related, the majority are not directly tied to food and flavour experiences. Existing tools, such as the Vividness Wine Imagery Questionnaire Revised (Croijmans & Wang, 2022) and the VFIQ (Patel al., 2015), are designed to assess imagery related to specific foods, but limited to address the broader spectrum of food imagery. This highlights a need for further research in this area. For instance, a novel scale should explicitly capture distinctions between orthonasal smell versus retronasal smell/flavour imagery. It should also incorporate oral-somatosensory perception, including texture and mouthfeel sensations, as independent dimensions. Additionally, measures like the SUIS, which assess individual's frequency or habitual use of MI, could benefit substantially from a food-specific adaptation. While it is plausible that MI for generic items is highly correlational with food-specific MI, empirical evidence supporting this assumption remains sparse. Developing a dedicated, multisensory food imagery scale could help to address these gaps and provide valuable insights into the role of imagery in driving food cravings and related behaviours.

Additionally, existing research has primarily focused on vividness measures of voluntarily activated MI, leaving a significant gap in understanding the differential role of involuntary and/or spontaneously occurring MI in influencing food cravings. While the SUIS measure provides valuable insights into an individual's habitual use of MI, its applicability to involuntary MI is limited. Some items on the SUIS may capture aspects of 'involuntary' MI (e.g., imagining a relative's face before visiting them), but others assess the tendency to engage in 'voluntary' MI in certain scenarios (e.g., visualising how new furniture might fit in a room). Methodologically, measuring involuntary MI presents challenges for self-reported scales. However, cognitive paradigm from prior research may offer promising alternatives for future studies (Djordjevic et al., 2004). Further research is needed to disentangle the combined and separate effects of voluntary, involuntary, and spontaneous-occurring MI on food cravings. This aligns with Spence's (2022) call to prioritise research into involuntary smell and taste imagery and their roles in shaping individual eating behaviours, paving the way for a deeper understanding of how multisensory MI influences food-related decisions and health outcomes.

## Ethical standards disclosure

This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving research study participants were approved by the University of Otago Ethics Committee. Informed consent was obtained from all participants.

## CRediT authorship contribution statement

**Mei Peng:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Jessica C. McCormack:** Writing – review & editing, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation. **Sashie Abeywickrema:** Writing – review & editing, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation. **Qian Janice Wang:** Writing – review & editing, Visualization, Methodology, Investigation, Data curation. **Reece Roberts:** Writing – review & editing, Visualization, Validation, Methodology, Formal analysis, Conceptualization. **Charles Spence:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Data curation, Conceptualization.

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## Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Mei Peng reports financial support was provided by Royal Society of New Zealand Marsden Fund. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.appet.2025.107990.

## Data availability

Shared on OSF with link included.

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